(12) **EUROPEAN PATENT APPLICATION**

(72) Inventor: Rozman, Allen Frank
1702 Waverly Court
Richardson, Texas 75082(US)

(74) Representative: Buckley, Christopher Simon
Thirsk et al
AT&T (UK) LTD.,
AT&T Intellectual Property Division,
5 Mornington Road
Woodford Green, Essex IG8 0TU (GB)

(54) Voltage control circuits.

(57) A voltage control circuit comprises a transformer (18) having at least a first primary winding (17) and at least first (20) and second (21) secondary windings, the winding direction of the second secondary winding (21) being opposite the winding direction of the first secondary winding (20). An input is coupled to the primary winding (17), first and second switch devices (11,12) are each coupled to the primary winding of the transformer, and a clamp capacitor is coupled to the transformer and at least one of the first and second switches. Each of the secondary windings (20,21) is coupled through a rectifier circuit and an output filter to a separate output. Means comprising a single feedback circuit (13,15), coupled on one side to one of the output filters and on the other side to control terminals of the first and second switches, cause the first and second switches to conduct current alternately. Although the circuit of the invention has only one feedback circuit, both outputs are capable of delivering different constant voltages (V_{out1}, V_{out2}) to different independent loads. The voltage magnitude supplied by each of the outputs depends on the ratio of the number of turns of the first (20) and second (21) secondary windings. Moreover, not only two, but any number of voltage outputs can be taken from the circuit by providing a corresponding number of secondary windings to the transformer.

FIG. 3
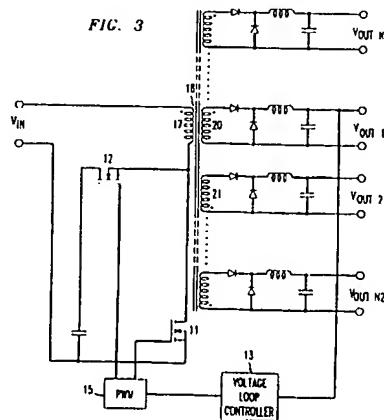
EP 0 602 835 A1

Technical Field

This invention relates to voltage control circuits and, more particularly, to DC-DC converters of a type known as "clamped mode" DC-DC converters.

Background of the Invention

The copending U.S.A. application of Jacobs et al., Serial No. 07/981,638, filed November 25, 1992, describes a DC-DC converter which uses a pair of FET switches, interconnected by a clamp capacitor, to drive a transformer. A pulse width modulator (PWM), which is included in a feedback loop, causes the FET switches to conduct alternately and to switch only when there is a low or possibly fro voltage across the FET switches. The zero-voltage switching results in high efficiency energy conversion, and the use of the external capacitance permits the circuit designer to reduce the rate at which drain-to-source voltages of either FET changes, thereby to reduce the level of conducted or radiated, high-frequency electromagnetic wave interference (EMI) which may be undesirably generated by the circuit. The application also discusses how output voltage ripple can be reduced.

Converters using a clamp capacitor to optimize energy transfer in this manner are generally known as "clamped mode" circuits. The copending U.S.A. application of Boyian et al., Serial No. 07/992,274, filed December 16, 1992, contains an analysis of the feedback loop of clamped mode circuits and describes how the voltage from the clamp capacitor can be fed to the feedback circuit to avoid circuit instabilities and to permit greater circuit design flexibility.

DC-DC converters are normally used as constant DC voltage power supplies. The desirability of having a DC-DC converter that could provide a number of different voltage outputs to a number of different independent loads has been recognized. There is a continuing need for such a circuit which has the advantages of clamped mode circuits, is of relatively simple construction and therefore relatively inexpensive, and which provides stable voltage levels to a number of independent loads that can be electrically isolated. With electrical isolation, noise, impedance changes, and the like from one load would not affect the power transmitted to another load.

Summary of the Invention

A voltage control circuit, in accordance with an illustrative embodiment of the invention, comprises a transformer having at least a first primary winding and at least first and second secondary windings, the winding direction of the second secondary winding being opposite the winding direction of the first secondary winding. An input is coupled to the primary winding, first and second switch devices are each coupled to the primary winding of the transformer, and a clamp capacitor is coupled to the transformer and at least one of the first and second switches. Each of the secondary windings is coupled through a rectifier circuit and an output filter to a separate output. Means comprising a single feedback circuit coupled on one side to one of the output filters and on the other side to control terminals of the first and second switches cause the first and second switches to conduct current alternately.

As will be described below, although the circuit of the invention has only one feedback circuit, both outputs are capable of delivering different constant voltages to different independent loads. The voltage magnitude supplied by each of the outputs depends on the ratio of the number of turns of the first and second secondary windings. As will be appreciated later, not only two, but any number of voltage outputs can be taken from the circuit by providing a corresponding number of secondary windings to the transformer. Regardless of the number of outputs taken, only a single feedback circuit or loop is used, and thus the structure of the DC-DC converter remains relatively uncomplicated. These and other objects, features and advantages of the invention will be better understood from a consideration of the following detailed description taken in conjunction with the accompanying drawing.

Brief Description of the Drawing

FIG. 1 is a schematic diagram of a DC-DC converter in accordance with one embodiment of the invention;

FIG. 2 is a schematic diagram illustrating a possible modification of the converter of FIG. 1;

FIG. 3 is a schematic diagram of a DC-DC converter for producing a larger number of outputs in accordance with another embodiment of the invention.

Detailed Description

Referring now to FIG. 1, there is shown schematically a DC-DC converter for supplying substantially constant output DC voltages V_{out1} and V_{out2} in response to an input DC voltage V_{in}, despite changes in input
5 voltage or changes in the characteristics of the loads to which the outputs may be connected. The circuit operates by alternately conducting current through a first switch 11 and through a second switch 12. The switches are controlled by a feedback circuit including a voltage loop controller 13, and a pulse width modulator (PWM) 15. The voltage applied to control terminals of the switches causes switch 11 to conduct for a fraction of each period of alternation known as the duty cycle D, while the switch 12 conducts for most
10 of the remaining interval of the period (1-D). A brief dead-time may be interposed between the conduction intervals to achieve low or possibly zero-voltage switching, i.e., switching during a time at which there is a zero voltage drop across the switch.

The switches 11 and 12 are typically power FETs and, more specifically, MOSFETs (for Metal Oxide Semiconductor Field Effect Transistor). The control terminals of such devices comprise their gate elec-
15 trodes. Thus, the gate drive signal applied by PWM 15 to switch 11 is a pulse having a time duration D, while the gate drive signal applied to switch 12 is a pulse having the time interval (1-D) minus the dead-time interval.

The current alternately flowing through the switches 11 and 12 drives the primary winding 17 of a power transformer 18 in such a manner as desirably to avoid saturation of the core of the transformer. The
20 transformer has separate secondary windings 20 and 21 wound in opposite directions as indicated by the dots, which are conventional symbols of winding direction. Secondary winding 20 is coupled through a rectifier circuit comprising rectifying diodes 23 and 24 to an output filter comprising an output inductor 25 and an output capacitor 26; secondary winding 21 is coupled through a rectifying circuit comprising rectifying diodes 27 and 28 to an output filter comprising an output inductor 30 and an output capacitor 31.
25 Separate outputs from the two output filters deliver constant voltages V_{out1} and V_{out2} to separate loads as shown. The two diodes of each rectifier circuit conduct current alternately such that the circuit constitutes a half-wave rectifier circuit. The output of secondary 20 is connected to a feedback circuit comprising a voltage loop controller 13 and the PWM 15. The output voltage V_{out1} drives the voltage loop control to vary the duty cycle at which switches 11 and 12 are switched to provide a controlled voltage output V_{out1} as is
30 usual with circuits of this type.

A clamp capacitor 28, connected in series with switch 12, charges to a steady-state voltage of $V_{in}/(1-D)$. This clamp capacitor voltage is then connected in series with the primary 17 of the transformer 18 during the (1-D) portion of the switching interval so as to transfer energy stored in the magnetizing inductance of the transformer to the output of the circuit. The application of input voltage V_{in} during the D portion of the
35 switching cycle, along with the capacitor voltage minus V_{in} applied during the (1-D) portion of the cycle, constitutes a means for transferring energy to the outputs during both portions of the switching cycle. Flux balance in the transformer 18 is achieved, and core saturation is avoided, because the average voltage applied to the primary winding 17 over a complete cycle is zero. A more detailed discussion of the circuit of FIG. 1 and its advantages is given in the aforementioned Jacobs et al. application.
40 As described in the aforementioned Boylan et al. application, the clamp capacitor 28 may be coupled to the PWM 15 to modify the phase and magnitude of energy applied to the switches 11 and 12 to stabilize the circuit and permit optimization of circuit parameters.

The present invention is based on the realization that a single feedback loop can be used to control both output voltages V_{out1} and V_{out2}. The two output voltages have relative values that are proportional to
45 the ratio of turns of the two secondary windings 20 and 21, so any of various combinations of output voltages can be produced. The outputs can be electrically isolated so that noise, impedance changes and the like from one load do not affect the power transmitted to the other load. This being true, the circuit of FIG. 1 offers obvious economic advantages over the use of separate converters to provide the two separate voltages V_{out1} and V_{out2}, and offers considerable electrical design advantages over a circuit having a single
50 output that is divided between two loads.

The following discussion is intended to demonstrate why two independent voltage-controlled outputs can be generated by a single converter using a single feedback loop. The FIG. 1 circuit is designed to avoid saturation of the core of the transformer by "resetting" the voltages of the transformer after each switching cycle. Thus, as is understood in the art, the product of the voltage across output inductor 25
55 during the D portion of the cycle and the duration of the D portion of the cycle equals the voltage across the output inductor during the (1-D) portion multiplied by the duration of the (1-D) portion. This is known as "volt-second balance," and the equation for such volt-second balance of the output inductor 25 coupled to secondary 20 is:

$$\left[V_{in} \cdot \frac{n_{s1}}{n_p} - V_{out1}\right] \cdot D = V_{out1} \cdot (1-D) \qquad (1)$$

where n_{s1} is the number of windings of secondary winding 20.

Solving for V_{out1} yields:

$$V_{out1} = D \cdot V_{in} \cdot \frac{n_{s1}}{n_p} \qquad (2)$$

where n_p is the number of windings of primary winding 17.

The equation for volt-second balance on inductor 30 coupled to winding 21 is:

$$\left[\left[\frac{V_{in}}{(1-D)} - V_{in}\right] \cdot \left[\frac{n_{s2}}{n_p}\right] - V_{out2}\right] \cdot (1-D) = V_{out2} \cdot D \qquad (3)$$

where n_{s2} is the number of windings of secondary winding 21.

Solving for V_{out2} yields:

$$V_{out2} = D \cdot V_{in} \cdot \frac{n_{s2}}{n_p} \qquad (4)$$

Therefore:

$$V_{out1} = V_{out2} \cdot \frac{n_{s1}}{n_{s2}} \qquad (5)$$

Equation 5 demonstrates that the output voltage V_{out1} is equal to the output voltage V_{out2} multiplied by the ratio of turns of secondaries 20 and 21. Thus by adjusting the ratio of turns one can develop whatever relative outputs V_{out1} and V_{out2} may be desired. The clamped mode circuit of FIG. 1 inherently regulates all outputs by applying a proportional volt-second product to each secondary winding over the entire input voltage range. This volt-second product is an average and converted to DC by the output filters. Another characteristic is that the control equation for the winding that transfers power during the (1-D) portion of the switching cycle is that of a "buck-derived" topology rather than a "fly back" topology. It can be shown that this will simplify the design of the feedback control loop and will improve certain performance parameters.

Another embodiment of a clamp mode converter is shown in a FIG. 2. In this configuration, the ground point for FET 35 is chosen so that its gate can be driven in a normal manner, referenced to ground, using a commonly available n-channel enhancement-mode FET. This avoids a more complex gate drive circuit referenced to a floating potential. As with FIG. 1, the output voltages is V_{out1} and V_{out2} are proportional to the number of turns on the two transformer secondaries.

The embodiment of FIG. 3 works in the same manner as that of FIG. 1 and therefore has corresponding reference numerals. Rather than having only two secondary windings, however, the FIG. 3 embodiment has a group of secondary windings that are wound in the same direction as secondary 21 and another group of secondary winding, wound in the same direction as secondary winding 20. Each secondary winding is coupled to an output filter through a half-wave rectifier circuit in the same manner as described before with

reference to secondaries 20 and 21. There is no need that the number of windings be balanced or be equal in any way. For example, there may be a number of secondary windings wound in the same direction as secondary 21 and only a single winding wound as secondary 20. The only requirement is that there be at least two secondary windings, driving two outputs, which are wound in opposite directions.

With the feedback taken from the output V_{out1}, the voltage of each of the other outputs V_{outN} is defined by:

$$V_{out1} = V_{outN} \frac{n_{s1}}{n_{sN}} \qquad (6)$$

where n_{s1} is the number of turns of secondary winding 20 (corresponding to output V_{out1}), and n_{sN} is the number of turns of the secondary winding corresponding to output V_{outN}. If the feedback were taken from another output, then the voltage of that output rather than V_{out1}, would constitute the voltage reference from which other voltages are computed.

Notice that with a given V_{out1}, the only variable is the turns ratio. Thus, output voltage V_{outN} is not dependent on the direction of winding of the corresponding secondary winding. It can be appreciated, then, that the invention offers the opportunity to reduce significantly the cost of equipment for supplying a number of different controlled voltages.

Various known modifications to clamped mode converters are applicable to the circuits of the invention. For example, a current loop controller can be added to the feedback circuit, as is known in the art. Full-wave rectifiers utilizing tapped or non-tapped windings could be used in place of the half-wave rectifiers, as is also known. Various other embodiments and modifications may be made by those skilled in the art without departing from the spirit and scope of the invention.

Claims

1. A voltage control circuit comprising:
   a transformer (18) having at least a first primary winding (17) and at least first (20) and second (21) secondary windings;
   the winding direction of the second secondary winding being the opposite of the winding direction of the first secondary winding;
   an input coupled to said primary winding;
   first and second switch devices (11, 12) each coupled to said primary winding of said transformer;
   a clamp capacitor (28) coupled to said transformer and to at least one of the first and second switches;
   first (23, 24) and second (27, 28) means for rectifying current of the first and second secondary windings, respectively;
   first (25, 26) and second (30, 31) output filters coupled, respectively, to said first and second secondary windings of said transformer;
   first and second outputs coupled, respectively, to said first and second output filters;
   and means comprising a single feedback circuit coupled on one side to one of said output filters and on another side to control terminals of said first and second switches for causing said first and second switches to conduct current alternately.

2. The voltage control circuit of claim 1 wherein:
   said input is adapted to accept DC input energy;
   and each of said outputs is adapted to deliver to appropriate loads DC output energy of predetermined voltage, whereby said voltage control circuit constitutes a DC-DC converter.

3. The voltage control circuit of claim 2 wherein:
   the output voltage of the first output is equal to the output voltage of the second output multiplied by the ratio of the number of turns of the first secondary winding to the number of turns of the second secondary winding.

4. The voltage control circuit of claim 3 wherein:
   said feedback circuit comprises a voltage loop controller coupled to an output filter and a pulse

width modulator, the pulse width modulator being coupled to said control terminals of said switches.

5. The voltage control circuit of claim 4 wherein:
the first rectifying means comprises alternately conducting first and second rectifying diodes coupled to the first output filter;
and the second rectifying means comprises alternately conducting third and fourth rectifying diodes coupled to the second output filter.

6. The converter of claim 1 wherein:
said transformer has a plurality of other secondary windings in addition to the first and second secondary windings;
each of the other secondary windings is coupled to another recitifier circuit, another output filter and other output terminals.

7. The DC-DC converter of claim 6 wherein:
each of the plurality of secondary windings drives a separate load coupled to the output terminals associated therewith, each of the loads being driven independently of other loads.

8. The converter of claim 6 wherein:
certain of said plurality of secondary windings are wound in the same direction as the first secondary winding, and others are wound in the same direction as the second secondary winding.

9. The converter of claim 6 wherein:
the single feedback circuit is coupled to the first output filter;
the output voltage of the first output terminals is V_{out1};
and the voltage V_{outN} of any of the other output terminals is determined by the relation:

$$V_{out1} = V_{outN} \frac{n_{s1}}{n_{sN}}$$

where n_{s1} is the number of windings of the first secondary winding and n_{sN} is the number of windings of the secondary winding corresponding to the output terminals having the voltage V_{outN}.

FIG. 1
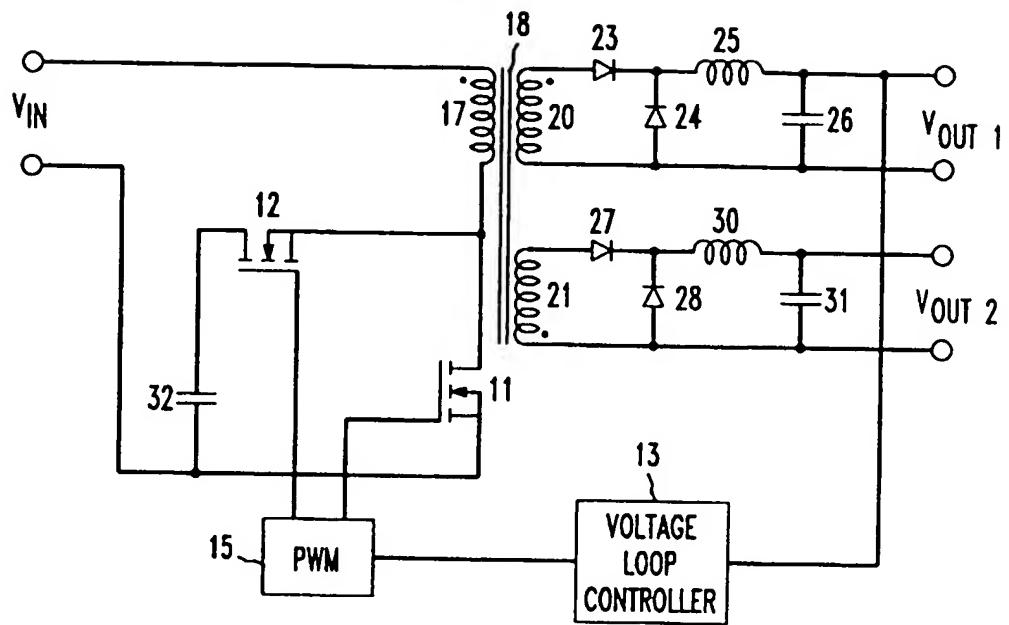
FIG. 2
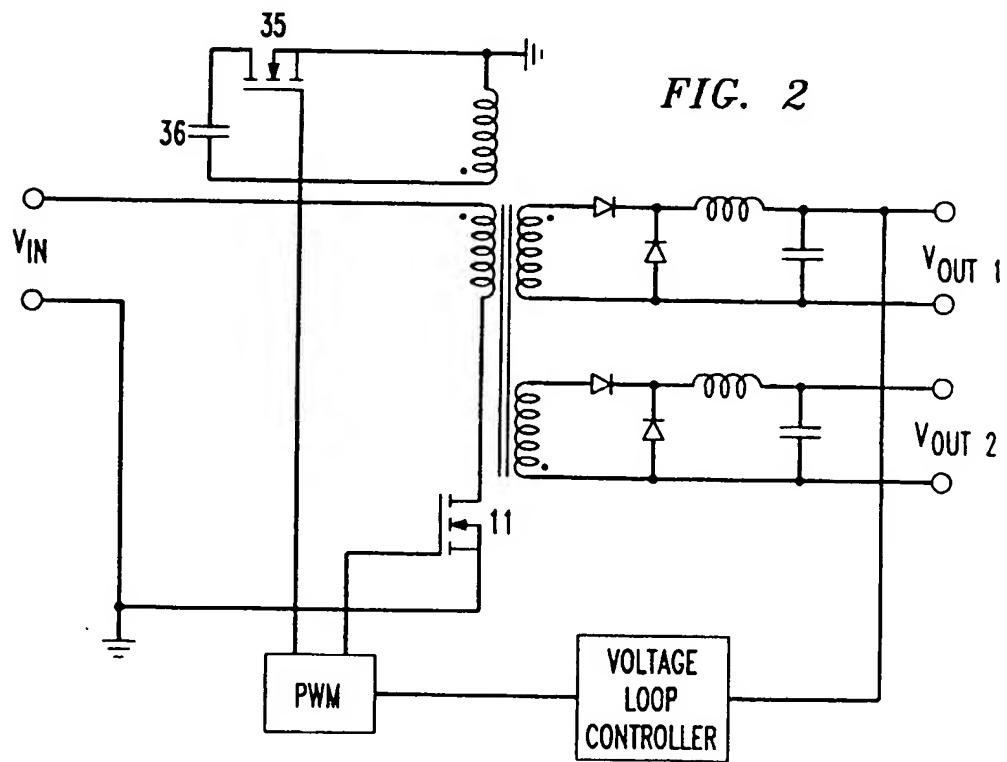
FIG. 3
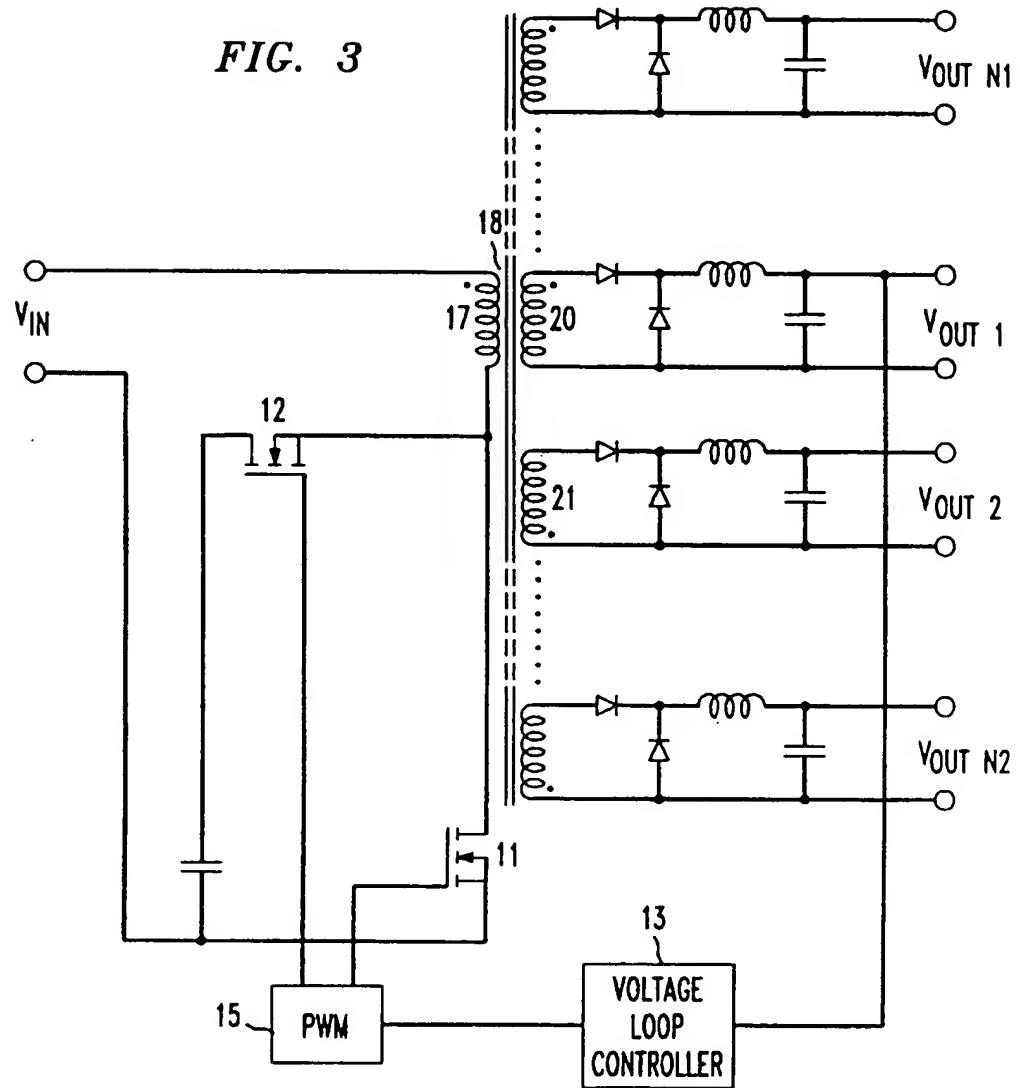
European Patent
Office

EUROPEAN SEARCH REPORT

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.5)
X	EP-A-0 474 471 (ITT INDUSTRIES) 11 March 1992 * the whole document * -----	1	H02M3/335

			TECHNICAL FIELDS SEARCHED (Int.Cl.5)
			H02M

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	11 February 1994	Bertin, M

CATEGORY OF CITED DOCUMENTS

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